LA-UR-20-25691
Approved for public release; distribution is unlimited.

Title:	Report on the recovery of legacy 1997-1998 Depth-of-Burial / Tunnel-and-Hole-Closure explosion data from the Kazakhstan former Soviet nuclear test site, Semipalatinsk.
Author(s):	Stead, Richard J.
Intended for:	Report
Issued:	2020-07-30

Report on the recovery of legacy 1997-1998 Depth-of-Burial / Tunnel-and-Hole-Closure explosion data from the Kazakhstan former Soviet nuclear test site, Semipalatinsk.

Richard Stead
2020/07/27

Background

In 1996, negotiations between the National Nuclear Center of the Republic of Kazakhstan (NNC), the U.S. Defense Special Weapons Administration (DSWA) and the U.S. Department of Energy led to an agreement for a joint series of experiments at the former Soviet nuclear test site Semipalatinsk (STS). These experiments had a dual purpose: to close holes and tunnels originally created for the purpose of testing nuclear weapons, and to characterize explosive sources at a former nuclear test site. This report covers the recovery of legacy data from the experiments conduct in 1997 and 1998.

Two teams collected data. Los Alamos National Laboratory (LANL), in collaboration with the NNC, collected the near-source (local) data out to approximately 20 km. Lamont-Doherty Earth Observatory (LDEO), with funding from Lawrence Livermore Laboratory (LLNL), also in collaboration with NNC, collected regional data, 200 – 1000 km distant, leveraging the KZ regional seismic network that LDEO had recently installed in collaboration with NNC. The two teams also worked together to some extent, regarding instrumentation and planning. This report primarily addresses the near-source data collected by the LANL/NNC team.

Existing documentation

The existing documentation is quite mixed. There are a few published journal papers (Myers, et al., 1999, Bonner, et al., 2001, Phillips, et al., 2001), and a few technical reports (Glenn and Myers, 1997, Pearson, et al.,1998, NNC, 1999). There are also a variety of informal reports (Demin, 1997, NNC, 1998), email messages, and field notes (LANL, 1997). In addition, some of the data files retain some identifying information, such as the serial number of the data acquisition systems (DAS), or the GPS coordinates of the station. For the recovery effort, this documentation was collected and some paper documents were scanned, converted to text and corrected, and translated from Russian if necessary.

Explosion Sources

Table 1 shows the list of known explosive sources related to these experiments. It is also known that many more holes were closed under the agreement, but the explosive sources in the table were specifically designated for the scientific work. These data were assembled from a variety of sources including reports from NNC, LDEO, LLNL and LANL, as well as LANL field notes, emails and similar documents. Not all documentation agreed on all items, therefore some judgement was used in selecting the values to report.

Table 1: Scientific shots

Date	DoY	Time	Hole	Charge (kg)	Depth (m)	Latitude	Longitude
1997-07-06	187	9:32:46.000	1381	52	500	49.883694	78.814750
1997-07-06	187	12:44:05.400	1381	51.2	300	49.883694	78.814750
1997-07-07	188	7:27:38.200	1311	91.2	210	49.941167	78.786000
1997-07-07	188	7:56:49.600	1311	91.2	50	49.941167	78.786000
1997-07-07	188	11:40:49.800	1349	106.8	585	49.879417	78.849333
1997-07-13	194	8:11:04.280	1389	5000	630	49.878556	78.760111
1997-08-03	215	8:07:20.040	1311	25000	50	49.941167	78.786000
1997-08-31	243	7:08:39.179	1381	25000	300	49.883694	78.814750
1997-09-28	271	7:30:15.126	1349	25000	550	49.879417	78.849333
1998-06-05	156	8:41:39.334	Tunnel 214	50	-	49.767943	77.990971
1998-07-13	194	10:44:56.363	1386	2028	20	49.880139	78.692056
1998-07-14	195	5:11:35.570	1327	2028	20	49.931472	78.787139
1998-07-14	195	8:19:39.296	1330	2028	20	49.912889	78.748778
1998-08-13	225	4:45:53.760	1383	140	0	49.872389	78.647778
1998-08-14	226	4:26:52.815	1409	2028	13	50.035667	79.011417
1998-08-14	226	5:39:24.970	1419	2028	2.5	50.057556	78.938694
1998-08-14	226	7:44:11.545	1383	223	190	49.872389	78.647778
1998-08-15	227	1:09:24.890	1071-bis	100	46	49.981028	78.755889
1998-08-15	227	2:40:59.116	1383	2028	14	49.872389	78.647778
1998-08-15	227	5:05:11.156	1389	2028	9	49.878556	78.760111
1998-08-22	234	5:00:18.904	Tunnel 214	100000	-	49.766667	77.990833
1998-09-17	260	7:19:40.551	1071-bis	25040	28	49.981028	78.755889

The details of the locations and timing are somewhat obscured by the passage of time. It is known from the extant documentation that some of the location data were considered poor quality at the time, and there were recommendations to revisit the issue. However, there is no evidence that location data were ever re-addressed. There is little information on the precision and accuracy of the locations and times, or by what means they were determined, or for location data, what geographic basis was used. Users of these data should be aware that locations are uncertain by between ± 10 m to ± 100 m, with the true uncertainty unknown. Uncertainties on source time include uncertainties on: the clock standard used for timing the detonation, how the timing of the fireset and detonation system were accounted for, and the factors such as the shape and detonation velocity of the charge. However, timing of the source should be sufficiently accurate for analysis for data at all but the closest stations, and is likely good to better than 1 s. Charge weights are also approximate and no effort was made at the time to be very precise on the amount of explosive used, nor to determine completeness of detonation after the fact. However, uncertainty on charge weight is likely less than 10%.

Sensor systems

A number of sensors were deployed near to the source, where near is defined as the range from 0 to 10 km. In 1997, 8 sensor systems were deployed, all in the Balapan portion of STS, where the shots were conducted; all 8 had seismic sensors only. Seven sensor systems had fixed locations and one sensor system was moved to be closest to the source for a number of the shots. In 1998, 9 sensor systems were deployed, part of the time in Balapan and part of the time in the Degelen portion of STS. In Balapan, all sensor systems were seismic and there were only 8; in Degelen, 7 sensor systems were seismic, one was infrasound, and one was CORRTEX. Table 2 is a summary of the sensor systems, and the site naming convention employed for this legacy data recovery effort. Figure 1 shows the locations of the boreholes and stations.

Table 2: Sensor system stations.

Station	Year	Latitude	Longitude	Elevation	Hole[1]	Sensor
BA1A	1997	49.879360	78.851533	330	1349	Accelerometer
BA1B	1997	49.942194	78.786944	335	1311	Accelerometer
BA1C	1997	49.881749	78.814000	333	1381	Accelerometer
BA1D	1997	49.878407	78.848502	331	1349	Accelerometer
BA2	1997	49.863888	78.870432	346		L4C3D Seismometer
BA3	1997	49.886971	78.910266	318		L4C3D Seismometer
BA4	1997	49.876499	78.766100	343		L4C3D Seismometer
BA6	1997	49.821277	78.753766	357		L4C3D Seismometer
BA7	1997	49.853111	78.984033	314		L4C3D Seismometer
BA8	1997	49.977749	78.761333	328		L4C3D Seismometer
BA9	1997	49.972082	78.960866	315		L4C3D Seismometer
BAX1A	1998	49.880000	78.692000	345	1386[2]	Accelerometer
BAX1B	1998	49.934400	78.786900	336	1327[3]	Accelerometer
BAX1C	1998	49.916100	78.748300	338	1330[3]	Accelerometer
BAX1D	1998	49.874800	78.647000	346	1383	Accelerometer
BAX1E	1998	50.038700	79.010700	302	1409	Accelerometer

BAX1F	1998	50.060300	78.938300	306	1419	Accelerometer
BAX1G	1998	49.984600	78.752200	325	1071-bis	Accelerometer
BAX1H	1998	49.879000	78.760000	342	1389[2]	Accelerometer
BAX2	1998	49.863600	78.870100	346		L4C3D Seismometer
BAX3	1998	49.916100	78.748300	338	[3]	L4C3D Seismometer
BAX4	1998	49.876600	78.763600	343		L4C3D Seismometer
BAX6	1998	49.821800	78.753100	357		L4C3D Seismometer
BAX7	1998	49.852600	78.984100	314		L4C3D Seismometer
BAX8	1998	49.977700	78.759000	327		L4C3D Seismometer
BAX9	1998	49.971900	78.958800	315		L4C3D Seismometer
DE1	1998	49.766666	77.990833	818		Accelerometer
DE2	1998	49.763333	77.981110	741		L4C3D Seismometer
DE2C	1998	49.763333	77.981110	741		CORRTEX
DE3	1998	49.794999	77.977777	633		L4C3D Seismometer
DE4	1998	49.869443	77.964527	566		L4C3D Seismometer
DE4I	1998	49.869443	77.964527	566		2 microphones
DE5	1998	49.855166	78.118388	554		L4C3D Seismometer
DE6	1998	49.730693	78.050972	619		L4C3D Seismometer
DE7	1998	49.775554	78.081110	646		L4C3D Seismometer

[1]Hole designation only provided for site “1” for each set of stations. Site “1” was moved to be close to each shot point, in most cases. Documentation also refers to site “1” as site “E”, for epicenter.

[2]Station location not recorded, other than “near hole X”. Station position given here as hole location.

[3]Station “3” was located adjacent to hole 1330 in 1998. For shots at hole 1330, the role of station “3” became that of station “1”, and mobile station “1” was located adjacent to hole 1327 to function as station “3”.

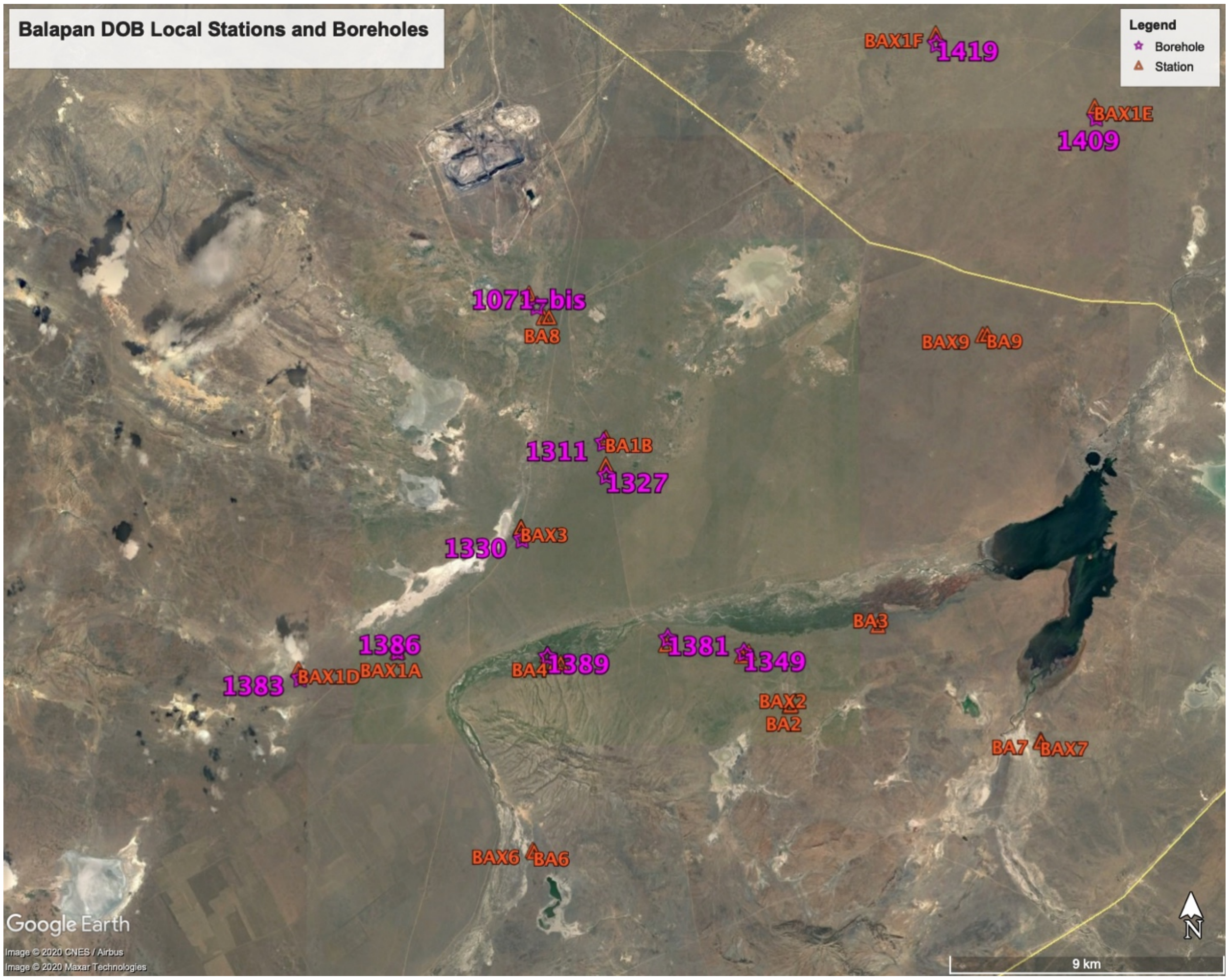

Figure 1. Local stations and boreholes. This Google Earth™ image shows the Balapan boreholes in which the depth-of-burial explosions of 1997 and 1998 were conducted, along with the local network stations deployed to record them. Note that some stations are co-located between 1997 and 1998, and that some of the stations are also essentially co-located with the boreholes. When symbols are close to each other, the software cannot display every label.

The station naming convention includes the original station number, a prefix BA (1997) and BAX (1998) for Balapan and DE for Degelen, and for station "1", a letter suffix intended to be unique for each position station "1" occupied for that series of explosions (station "1" was the mobile station). There is also a letter suffix "C" for CORRTEX and "I" for infrasound. All seismometers and accelerometers are 3-component sensors, vertical, north and east, and all DAS are Reftek® RT72A-08.

For these recorders, the first 3 channels are 16-bit and the second 3 channels are 24-bit. In all cases, the 24-bit channels (4, 5 and 6) were used. Documentation often, but not always, includes the serial numbers of the recording systems and sensors, as well as serial numbers for things like memory cards inside the recording systems. Any differences in bitweight per channel or per system for the recorders are unrecoverable, since the recorders and their documentation were disposed of long ago. Therefore, the main advantage of having recording system serial numbers is to be able to associate data file containing recorder serial numbers with the proper station. Memory card serial numbers are of no use today, since the memory cards themselves are long gone and no extant data are associated with those numbers. Sensor serial numbers can be used to track down per-channel calibration information from that time and associate those calibrations with sensor system response. Table 3 shows the DAS serial numbers, and sensor type and serial number, if known. Note that there were some replacements of equipment during the experiments.

Table 3: Instruments and serial numbers

Station	DAS serial	Sensor type and serial
BA1A	415	FBA 506
BA1B	415	FBA 506
BA1C	415	FBA 506
BA1D	415	FBA 506
BA2	470, replaced with 459	L4C3D 625
BA3	510	L4C3D 627
BA4	473	L4C3D 619
BA6	405	L4C3D 621
BA7	409	L4C3D 622
BA8	470	L4C3D 620
BA9	414	L4C3D 623
BAX1A	566	FBA 508
BAX1B	566	FBA 508
BAX1C	566	FBA 508
BAX1D	566	FBA 508
BAX1E	566	FBA 508
BAX1F	566	FBA 508
BAX1G	566	FBA 508
BAX1H	566	FBA 508
BAX2	459	L4C3D 625
BAX3	510	L4C3D 627
BAX4	473	L4C3D 619
BAX6	405	L4C3D 621
BAX7	409	L4C3D 622
BAX8	509	L4C3D 620
BAX9	414	L4C3D 623
DE1	415, replaced with 414	Accelerometer 16
DE2	459, replaced with 566	L4C3D 620
DE2C	509	CORRTEX ATO
DE3	510	L4C3D 619
DE4	473	L4C3D 627
DE4I	459	2 microphones, “north” and “south”

DE5	508	L4C3D 628, replaced with 172
DE6	405	L4C3D 621
DE7	409	L4C3D 622

"FBA" is a force-balance accelerometer, originally of unknown make and model. Through personal communications (Baker, D and Pearson, C, 2020) it was learned that the FBA was a Terratech (Terrascience Systems Ltd) model SSA-302 50-Hz triaxial force-balance accelerometer. The acceleration response of this instrument is documented elsewhere as having 2 poles at $-219.79 \pm 250.18i$ (the addition of 2 zeroes would make the response displacement). These poles are consistent with the "50-Hz" designation (The square root of the sum of the squares of the real and imaginary parts of either pole is approximately $2\pi f$ where f is 50 Hz. However, this type of instrument is documented by researchers elsewhere as having a sensitivity of 1.25, 2.5 or 5 V/g, while the foregoing personal communications indicate that the FBAs used here had a sensitivity of 1 V/g. In addition, there is one other sensor deployed and documented only as "Accelerometer" (or "25g accelerometer") which also was an accelerometer of unknown type, make and model. It has since been identified, partly because similar systems still exist at LANL, as a field package assembled by EG&G containing 3 orthogonal Endevco® 2262-25 piezoresistive accelerometers. These accelerometers tend to have a wide range of response, (nominally 20 mV/g, but can vary +/-30%) and therefore the response remains somewhat uncertain. "L4C3D" is a Mark Products L4 1-Hz low-gain, short-period seismometer. Mark Products was acquired by Sercel, and the L4 has long been discontinued, but they offer a similar instrument, the GS-1. Both the accelerometers and the seismometers are 3-component instruments, vertical, north and east. I was unable to find any calibration information for the accelerometers. The L4C3D appears to be a standard model with a nominally 5500 Ω coil and 1 kg mass per component. The relevant nominal response information includes: natural frequency $f_0 = 1.0$ Hz, damping = 0.707 of critical, sensitivity (generator constant) G = 276.8 V-s/m, free motion of the mass = 6.25 mm, coil inductance = 6.0 H. The pole-zero response has 2 poles at $-4.44 \pm 4.44i$ and 2 zeros at 0. The per-channel sensor response will be within 10% of this for these sensors. Note that other common models of the L4 include different coils, for example PASSCAL (Portable Array Seismic Studies of the Continental Lithosphere), the IRIS (Incorporated Research Institutions for Seismology) portable instrumentation facility, used to offer an L4 with 2000 Ω coils and G = 166.9 V-s/m. I could find no information regarding the microphones used for the Tunnel 214 100 t shot. Another LANL program has done extensive work on the CORRTEX from that shot, and no further work is reported herein. CORRTEX (Continuous Reflectometry for Radius versus Time Experiment) is a time-of-flight electrical technique for measuring the length of a cable as a function of time as it is crushed by an explosive shock front.

The Reftek® 72A-08 was a very common digital seismic DAS at the time of these experiments. It was very commonly used in temporary deployments, and even for some permanent stations. A few are likely still in use in local networks in third-world nations. However, Reftek® obsoleted these long ago. It was available in 3- and 6-channel models and had 16-bit and 24-bit options. The version used for these experiments had 3 16-bit channels for channels 1-3 and 3 24-bit channels for channels 4-6. The experiments only used the latter. The bitweight for the digitizer was nominally 1.907 µV/count. All channels would have been within 1% of nominal. The system could be configured in triggered or continuous modes. In most cases for these experiments, the systems were configured with triggered mode. This does lead to problems where not all stations trigger, often because the station site is noisy or the received signal was below the triggering threshold. This was a frequent problem with these experiments. In addition, the triggered segments are often quite short (30 s) and have very little pre-event signal (3 s). For all experiments, the sampling rate was set to 500 samples/s. Exceptions were CORRTEX, set at 1000 samples/s and infrasound, set at 50 samples/s. 500 samples/s provides a Nyquist frequency of 250 Hz, and accounting for the anti-aliasing filters, means data can be analyzed up to at least 200 Hz. An individual L4C3D channel may have spurious resonance below this frequency, but more likely does not. Therefore, it is expected that the data will give good results up to at least 200 Hz.

To determine the sensitivity of the accelerometers, the existing accelerometer waveforms for the largest explosions were examine for evidence of spall. On a raw accelerometer record, spall appears as a relatively flat portion of the waveform, having a large negative value (positive if the sensor is inverted) and near to the start of the record, just after the arrival of the main positive shock. Spall occurs when a portion of the earth's surface above the explosion has separated, and therefore is in free fall, primarily under the influence of gravity alone. During this time, the acceleration is therefore exactly 1g, and the accelerometer will produce a relatively constant signal of that amplitude. In 1997, there were 3 explosions of 25 tons, which is large enough to cause significant spall that could be measured by an accelerometer sufficiently close to the epicenter (see Table 1). For the first of these, no accelerometer record was found. For the second, there is an excellent spall record lasting 18 samples in the 500 sample/s waveform. The average of those samples is -438200 digital counts, and the pre-event background signal has an average of -1500 digital counts. Given the RT72A-08 bitweight of 1.907 μV/count, this yields 0.833 V/g for the Terratech SSA-302 serial number 506, which is significantly different from that expected. The third explosion also has a digital record, but the spall there has a duration of only 5 samples at 500 samples/s. Again, the average is -457700 counts, background is -1500 counts, yielding 0.870 V/g, consistent with the second event, but less certain due to fewer data points. Larger explosions create spall of longer duration over wider areas, therefore a record of spall is not anticipated for the explosions smaller than 25 tons, given the brief duration for the 25-ton explosions. In 1998, there was only one explosion of 25 tons in Balapan. Unfortunately, no accelerometer record was found for that event. The Terratech used there is documented as serial number 508, versus 506 for 1997, but the lack of a record that could be used for calibration purposes and the possibility that 506 or 508 could be a typo for the other, both accelerometers will be considered to have the same response here. For the accelerometer deployed at Degelen for the 100-ton Omega-1 explosion in Tunnel 214, the sensor is the one documented only as "accelerometer", "25g", and serial number "16". The record has a clear spall signal, however the amplitude of this signal is much smaller than that of the Terratech FBAs. The duration of the signal is 36 samples at 500 samples/s, with an average amplitude of -5615.78 counts and -2683.28 counts for the pre-event background. Again, assuming the RT72A-08 bitweight of 1.907 μV/count, this yields 0.0056 V/g. Therefore, for the purposes of this data set, we will use the Terratech poles that were found elsewhere and the 0.833 V/g sensitivity found here for all Balapan accelerometer records, and a sensitivity of 0.0056 V/g for the Degelen accelerometer. The corner frequency for the Degelen accelerometer is unknown, leaving the poles to be used unknown. It may be safest to assume that the sensor was flat beyond the capacity of the data recorder, therefore, it is assumed here that the sensor in question is a 1000-Hz accelerometer, but having the same damping as the Terratech. These assumptions cannot be justified, but some value must be asserted to develop an instrument response and complete the metadata.

Local Waveforms

Waveforms were found in many states and formats. The following formats were found: Reftek® raw (".ref") format, PASSCAL SEGY format (this is a major modification of the SEGY format, intended for archiving data from certain types of PASSCAL temporary deployments out of IRIS), and SAC (Goldstein, et al., 2003). Handling of the waveform data appears to be as follows:

1) Data were recorded in triggered mode on the Reftek® 72A-08 systems using SCSI-mounted Reftek® disk drives. The triggering configuration generally resulted in waveforms of approximately 33 seconds in length; 3 seconds before and 30 seconds after the trigger.
2) They were then transferred, still as Reftek®'s proprietary .ref format, to SCSI-mounted Exabyte tape drives for the purpose of transfer and archive.
3) Once then transferred to the destination system, the files were converted to PASSCAL SEGY format, but apparently no further processing was done to the data at this point.
4) Later, the data were converted to SAC format, and a number of operations were performed on the data to in order to correct the waveforms to physical units. There is no provenance information extant to help determine what processes have been executed on the data found in SAC files. Therefore, the data may be raw, partially processed, or converted by some means into a form of physical units.

After reviewing the complete inventory of all recovered waveforms, all SAC format waveforms are fully represented (station and time) among the PASSCAL SEGY and raw Reftek® format waveforms. Given additionally questions about provenance for the SAC waveforms, all recovered SAC files are therefore ignored for the purposes of this recovery project. However, neither the PASCCAL SEGY nor the raw Reftek® format waveforms comprise a complete set by themselves. Therefore, both sets were fully converted to standard format, with duplication between them subsequently eliminated. The final set is the most complete set of these data available from all recovered sources, and all of the times series therein correspond to the data as recorded originally in the field (known provenance).

It is noted here that no QA/QC has been performed on the waveform samples themselves. This work has focused on resolving metadata issues and correctly tying waveforms to metadata (broadly speaking, "referential integrity"). Notes from the time make broad reference to certain quality issues, such as noisy channels, dead channels, and the like. These issues are always expected to some extent in such data, and researchers will be familiar with them.

Numerous problems were indeed found in the process of resolving the metadata and its ties to the waveforms. The primary link between the waveforms and the metadata was through the serial numbers of the data recorders. This was most direct in the case of the raw Reftek® data. The .ref format includes the serial number in header information. This serial number along with the file's time information can be extracted from the binary file to connect the waveform to a known sensor configuration. This is why it was critical to establish the timeline for the equipment deployment as part of constructing the metadata. In many cases, the raw Reftek® files had no other indication regarding which sensor system they belong to. In addition, while many of the raw Reftek® files have GPS coordinates in them, this is also often not the case, and the coordinates provided tend to be fairly inaccurate, since the GPS on the recorder is primarily intended to synchronize the clock, not provide a precise location. Such coordinates, when present, do provide a quality check regarding the equipment timeline, and indeed contributed to certain adjustments of that timeline.

Regarding the PASSCAL SEGY formatted files, this was a little less straightforward. The software used to accomplish this when the data were first recorded did generally place the recorder serial number both in the file name and in one of the modified fields of the header, but this was not the case in a few examples. More importantly, none of the headers in these files ever included the station coordinates (despite fields being available for this purpose), eliminating that quality check. Therefore, for these files, the serial number alone must suffice.

Several files were found to have time errors. The most prominent were files having the year '1988' instead of the actual year (1997 or 1998). The original cause of this error is unknown, but there were references to this possibility in some notes from the original work, and after some checking, it was verified that only the year was the problem in most cases. When only the year was in error, that was corrected to the proper year, and the data integrated with the rest of the recovered data. In some cases, both the year and the date are obviously incorrect, and occasionally quite corrupted (years in the distant future). In these cases, the correct date could not be determined, nor could the time be verified. All such data were set aside and not integrated. Because the equipment was configured only for triggered operation, there are not intervening logs or gaps in the correct data that could provide clues regarding the actual times. The only hope for resolving such issues would be to determine the correct times in some way from signals contained in the waveforms, which is well beyond the scope of this recovery effort.

Regional Waveforms

At the time of the original work in 1997, LDEO had recently installed a small, permanent, regional network in Kazakhstan, using the FDSN network code KZ. In collaboration with LLNL, LANL and NNC, this network was leveraged to make regional recordings of these explosions. In addition to this network, there were a few other open global stations operating at the time within regional distances. All of these data are available at the IRIS DMC (Data Management Center). A copy of all of these data is also maintained locally at LANL.

These stations were configured for continuous operation, and therefore the entire data volume for 1997 and 1998 is fairly large, at least 200 GB. Mark Leidig of ARA undertook to select appropriate segments of data for the explosions and to reformat the data as SAC. His selections are used here in preference to the continuous data available at IRIS and at LANL. Researchers who may need more of the continuous data are referred to the IRIS DMC.

Table 4 lists the regional stations available at the IRIS DMC for this time period. Note that some stations are occupied by multiple FDSN networks, and several stations may be known by more than one station code. Distances to Balapan are only given to the nearest 10 km, because the boreholes used in these experiments are about that widely spread. The network XW97, listed separately at the bottom of the table, is known by the FDSN network code "XW", but only for the time period 1997 – 2001. This is a PASSCAL temporary deployment named "Multidisciplinary Investigation of the Mountain Building in the Tien Shan", that happened to be deployed within regional range during the same time period. There are also several arrays listed. Three of these are what the Soviet Union called "necklace" arrays; 6-element mini-arrays around the original Soviet stations from the testing era. The stations and their mini-arrays were all re-occupied for at least a portion of the time for the KZ network. Additionally, the Kurchatov cross-array, KUR<nn> was also re-occupied. Regional stations are listed in Table 4 and shown in Figure 2.

Table 4. Stations at regional distance from Balapan, where data are available at the IRIS DMC for 1997-1998.

FDSN Network Code(s)	Station Codes(s)	Distance to Balapan (km)
II, KN	AAK	870
KN	AML	950
KZ	BAY, BAYK	250
II, KZ	BRV, BRVK	680
KZ	CHK4, CHKZ1	700
KZ	CHK5, CHKZ2	700
KZ	CHK6, CHKZ3	700
KZ	CHK7, CHKZ4	700
KZ	CHK8, CHKZ5	700
KZ	CHK9, CHKZ6	700
KZ	CHK, CHKZ	700
KN	CHM, CHMS	830
KN	EKS2	890
KN	KBK	860
KR	KDJ	870
KZ	KKL	250
KZ	KUR01	90
KZ	KUR02	90
KZ	KUR03	90

KZ	KUR04	90
KZ	KUR05	80
KZ	KUR06	80
KZ	KUR07	80
KZ	KUR08	80
KZ	KUR09	70
KZ	KUR10	70
KZ	KUR11	80
KZ	KUR12	80
KZ	KUR13	80
KZ	KUR14	80
KZ	KUR15	80
KZ	KUR16	80
KZ	KUR17	80
KZ	KUR18	80
KZ	KUR19	80
KZ	KUR20	90
KZ	KUR21	80
KZ	KUR22	80
KZ	KUR23	80
KZ	KUR24	80
KZ	KUR26	80
KZ	KUR27	80
KZ	KUR28	80
II, KZ	KUR, KURK	90
KN	KZA	910
IU, KZ	MAK, MAKZ	420
KZ	PDG, PDGK	730
KC	TARG	910
KZ	TLG	750
KN	TKM2	810
KN	UCH	910
KN	ULHL	870
KN	USP	800
KZ	VOS4, VOS1	630
KZ	VOS5, VOS2	620
KZ	VOS6, VOS3	620
KZ	VOS7, VOS4	630

KZ	VOS8, VOS5	630
KZ	VOS9, VOS6	630
KZ	VOS, VOSK	620
IC	WMQ	960
G	WUS	970
KZ	ZRN4, ZRNK1	750
KZ	ZRN5, ZRNK2	750
KZ	ZRN6, ZRNK3	750
KZ	ZRN7, ZRNK4	760
KZ	ZRN8, ZRNK5	760
KZ	ZRN9, ZRNK6	760
KZ	ZRN, ZRNK	750
XW97	ATUS	1150
XW97	BCHU	1120
XW97	DGE	1040
XW97	KAI	970
XW97	ANA	800
XW97	KAR	830
XW97	KASH	1180
XW97	KAZ	1010
XW97	KDJ	870
XW97	KHA	730
XW97	KSA	930
XW97	NRN	970
XW97	PDG	730
XW97	WQIA	1160

A few of these stations also include infrasound channels. Sample rates were varied at the KZ network channels to capture higher-frequency data during certain explosions at Balapan. For complete information, researchers are referred to the IRIS DMC.

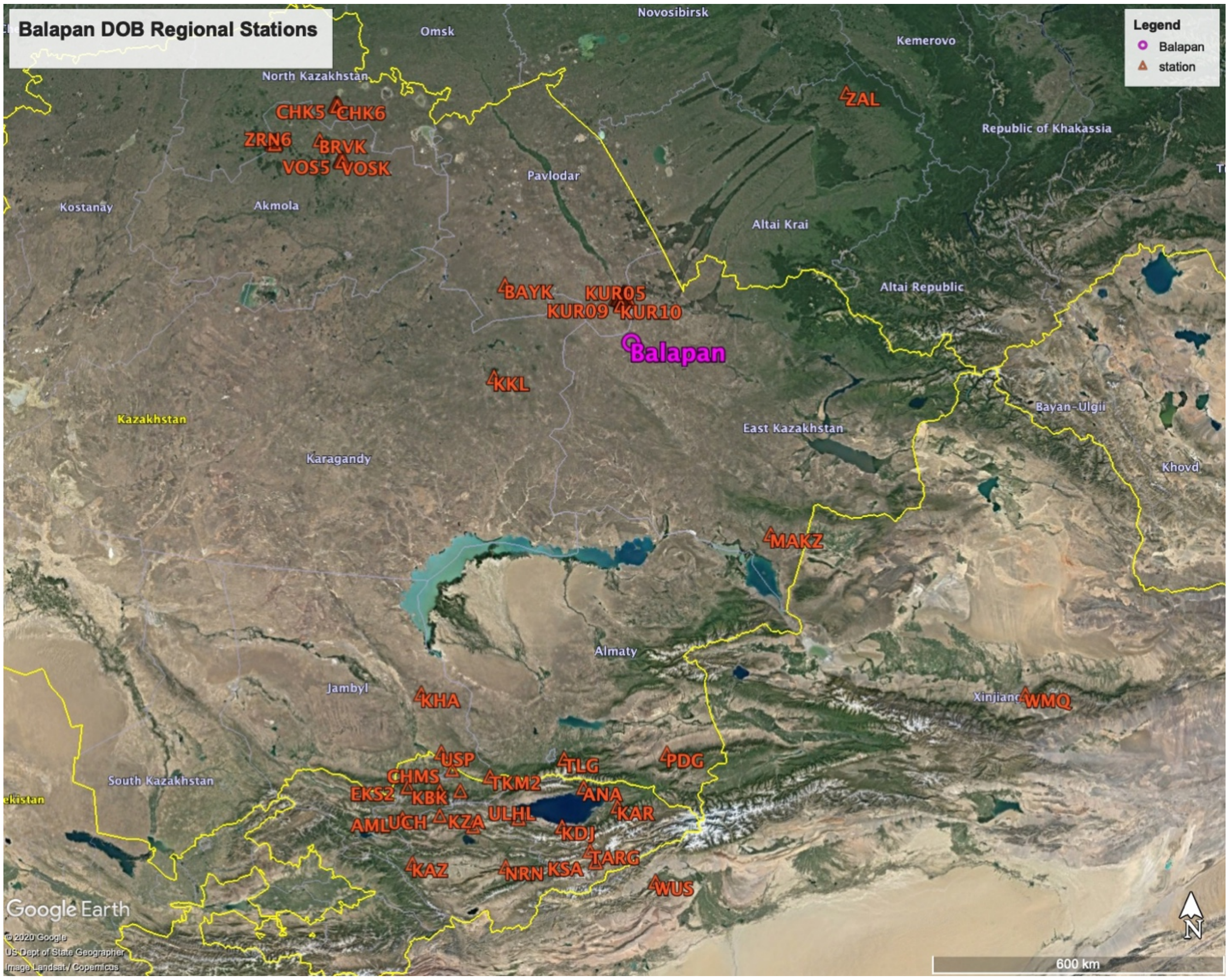

Figure 2. Regional stations. This Google Earth™ image shows all regional stations (out to approximately 10 degrees of arc) in operation during 1997-1998. This includes the Kazakh regional network (FDSN network code KZ) leveraged specifically for these experiments. Note again that close symbols do not allow all labels to be displayed. Also note that the mini-arrays around VOSK, ZRNK and CHKZ are very small, leading to 7 symbols each that almost entirely overlap, and the Kurchatov cross-array, while much larger, also has a lot of symbol overlap at this scale.

Data Product

The recovered waveforms and metadata have been compiled into a data product for distribution. This data product contains both the local waveforms and the regional waveforms. The product is comprised of 6 elements: the local waveforms in SAC format and in miniSEED (SEED is Standard for the Exchange of Earthquake Data, see IRIS, 2012) format, the regional waveforms in SAC format and in miniSEED format, a small collection of relevant documents, and a collection of both the explosion origin data and the local station metadata in CSS3.0 (Anderson, et al, 1990) format.

The local waveform data include every waveform segment captured by the triggered stations. These were first added to the LANL integrated database, and then exported into the necessary formats from there. For both the SAC format and miniSEED format, the waveforms are organized by event, and the large number of other triggered waveforms are collected in a single "other" directory. These exports were created by Christine Gammans of LANL using utilities available in the Python software package ObsPy (Beyreuther, 2010) and other Python packages.

The SAC files for the regional waveforms were compiled by Mark Leidig of ARA. These were compared the contents of the local LANL database, and they match very well. The local LANL database has a handful of additional channels that are not necessarily relevant. These same SAC files were then converted directly to miniSEED by Christine Gammans using tools similar to those she used for exporting the local waveforms.

The origin information assembled in the LANL integrated database was exported in CSS3.0 format (tables event, origin, origerr and netmag). Note that origin information from other authorities, such as the published bulletins of the United States Geological Survey (USGS) and International Seismological Centre (ISC) has been included. The station metadata for the local stations has also been exported as CSS3.0 tables (tables network, affiliation, site, sitechan, sensor and instrument), along with the instrument response information in the format formats (Wüster, et al., 2002, Appendix) of the CTBTO IDC (Comprehensive Nuclear Test-Ban Treaty Organization, currently operating as the Provisional Technical Secretariat, International Data Center), which is based on the instrument response format originally designed for CSS3.0. In addition, text files providing glossary descriptions of terms used in the CSS3.0 tables are also provided. All of these files are ASCII text files.

References

Anderson, J., W.E. Farrell, K. Garcia, J. Given, H. Swanger (1990). Center for Seismic Studies Version 3 Database: Schema Reference Manual, SAIC technical report C90-01.

Beyreuther, Moritz, Robert Barsch, Lion Krischer, Tobias Megies, Yannik Behr and Joachim Wassermann (2010), ObsPy: A Python Toolbox for Seismology, SRL, 81(3), 530-533.

Bonner, Jesse L., Pearson, D. Craig, Phillips, W. Scott & Taylor, Steven R. Shallow Velocity Structure at the Shagan River Test Site in Kazakhstan. *Pure appl. geophys.* **158,** 2017–2039 (2001). https://doi.org/10.1007/PL00001139

Demin, V, 1997. The results of the geophysical explosions in boreholes at the site Balapan. Report on contract No DSWA - 0094/1 of 23 April 1997, phase 3. Single table, translated from Russian to English by Richard Stead.

Goldstein, P., D. Dodge, M. Firpo, Lee Minner (2003) "SAC2000: Signal processing and analysis tools for seismologists and engineers, Invited contribution to "The IASPEI International Handbook of Earthquake and Engineering Seismology", Edited by WHK Lee, H. Kanamori, P.C. Jennings, and C. Kisslinger, Academic Press, London.

Glenn, L. A. and S.C. Myers, 1997: Depth of Burial experiments at Balapan. Report UCRL-JC-128313, Lawrence Livermore National Laboratory. Available at https://www.osti.gov/servlets/purl/653010

IRIS (2012). SEED Reference Manual: Standard for the Exchange of Earthquake Data, SEED Format Version 2.4, August, 2012, see https://ds.iris.edu/ds/nodes/dmc/data/formats/seed, last accessed 2020/07/25.

Kim, W.Y., 1997. DOB. Web site: https://www.ldeo.columbia.edu/~wykim/JSP/Dob/dob.html last accessed 2020/06/10.

Los Alamos National Laboratory Staff (LANL), 1997. Field notes from Depth of Burial experiments.

Myers, Stephen C., Walter, William R., Mayeda, Kevin & Glenn, Lewis. (1999). Observations in Support of Rg Scattering as a Source for Explosion S Waves: Regional and Local Recordings of the 1997 Kazakhstan Depth of Burial Experiment. Bull. Seismol. Soc. Am.. 89 (2): 544-549.

National Nuclear Center of the Republic of Kazakhstan (NNC), 1998. Daily reports of 1998 explosion results. Translated from Russian to English by Richard Stead.

National Nuclear Center of the Republic of Kazakhstan (NNC), 1999. A 100-tonn high explosive seismic calibration test in tunnel 160 and a post-test geologic survey of tunnel 214, Final report for Omega-2. Report under Contract DSWA01-98-C-0016-P00006. CLIN 0076, Kurchatov, Republic of Kazakhstan. In English, with 2 Appendices.

Pearson, D C, Phillips, W S, Glenn, L A, and Denny, M D., 1998: "The source depth of burial experiment at Shagan River, Kazakstan". Presented at the 20th Seismic Research Symposium on Monitoring a CTBT, Santa Fe, New Mexico, United States. Los Alamos National Laboratory Technical Report LA-UR-98-3058. Available at https://www.osti.gov/servlets/purl/319614

Phillips, W. Scott, Hartse, Hans E. & Steck, Lee K. Precise Relative Location of 25-ton Chemical Explosions at Balapan Using IMS Stations. *Pure appl. geophys.* **158,** 173–192 (2001). https://doi.org/10.1007/PL00001154

Philips, W.S., D.C. Pearson, C.L. Edwards, D.F. Baker and M.D. Denny, 1998. Source Depth of Burial Experiment at Balapan, Web site: https://public.lanl.gov/geophysics/geophysics/Posters/Scott/poster.html Last accessed 2020/06/10.

Wüster, J, M. Bahavar, A. Boresch (2002). IDC documentation: Configuration of IDC Processing Data Files Revision 1, IDC6.2.4r1, Angewandte Wissenschaft, Software und Technologie GmbH (AWST).